

DRILLING OF CARBON FIBRE REINFORCED POLYMER MATERIALS - A REVIEW

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ABSTRACT

Drilling is a secondary manufacturing process used for the finishing of the parts done in the primary manufacturing. For drilling of traditional materials, there are several techniques available to attain the objective of good circularity of the hole without any damage. Drilling of the CFRP material is difficult, because of its anisotropic and non-homogeneous in nature. Carbon fibre reinforced materials extensively used in the aerospace industries, because of its specific properties in strength and stiffness. Hence, the drilling of CFRP requires a lot of research for using in the aerospace industry. The principal aim of this paper is to present an extensive literature report in the drilling of CFRP and that includes the studies on different input variables such as machining parameters (speed, feed and drill point angle) and drill bit on the drilling induced damages. Also, the study focuses effects of input variables on delamination and hole circularity and induced thrust force and torque.

KEYWORDS: CFRP, Delamination, Drilling, Thrust Force & Surface Roughness

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INTRODUCTION

Carbon fibre reinforced plastic (CFRP) composites have been widely used in engineering application such as automotive, aircraft and manufacture of spaceships and sea vehicles' industries due to their significant advantages over other materials. They provide high specific strength/stiffness, superior corrosion resistance, light weight construction, low thermal conductivity, high fatigue strength, ability to char and resistance to chemical and microbiological attacks [1,2]. As a result, advanced composite materials make about 50% of the structural weight of Boeing 787 and Airbus A350XWB. Generally, parts made of composites produced to a near-net shape, but additional machining operations are often required to facilitate component assembly [3-4]. Among those operations, drilling is one of the most common. It is usually required to allow the application of screws and rivets in the assembly of parts. This can be carried out with conventional tools and machining equipment, sometimes with some adaptations [5]. However, due to the heterogeneity, anisotropy, and high abrasiveness of fibres, drilling operation can lead to different kinds of damages [6]. It exhibits considerable problems in a drilling process such as delamination, fibre pull-out, hole shrinkage, spalling, fuzzing and thermal degradation [7]. Among the defects caused by drilling, delamination around the drill hole site appears to be the most critical, which can result in a lowering of bearing strength and can be detrimental to durability by reducing the in service life under fatigue loads [8]. Delamination can often become a limiting factor in the use of FRPs for structural applications. Therefore, addressing how to improve the quality of the holes in the drilling of FRPs is imperative [9]. As an example, over a 100000 holes are required for small single engine aircraft, and in a large transport aircraft millions of holes are drilled. The delamination damage is associated with 50-60% of all parts rejections during final assembly of an aircraft [10]. Many references have shown that the thrust force is also major factor responsible for drilling-induced delamination and it mainly depends on drill materials, drill geometry and feed rate [11].

In addition to delamination, sub-surface deformation is another important drilling induced damage while composite machining, Interfacial deboning, matrix deformation, fiber pullouts, matrix crazing, cracking, hole shrinkage and spalling are few examples of sub-surface deformations [12]. So, in order to improve the product performance and structural integrity of machined holes, the material defects such as sub- surface deformation and delamination has to be trimmed-down by proper selection of cutting parameters, tool geometries, tool types and cutting conditions [13]. Spalling and fuzzing are considered as the major exit damage mechanisms during drilling of FRP composite laminates and these damages increase with an increase in feed rate and decrease in spindle speed. Spalling at hole exit is usually a severe damage and it is bigger for UD-CFRP laminate as compared to multi-directional CFRP laminate under the same drilling conditions [14].

The increasing popularity of carbon composites in the industry and the constant need to maximize productivity has led researchers to look at methods of optimizing the drilling process. Therefore, the present work provides a detailed review of drilling on CFRP composite

DRILLING OPERATION

Although several non-traditional machining operations such as laser machining, water-jet machining and electrical discharge machining have been developed for application to hole-making of composite laminates, mechanical drilling operations Using conventional or special drill bits are the primary applications for composite laminates [3]. The factors such as cutting parameters, tool geometries, tool materials, thrust force and torque greatly influence the drilling of CFRP laminates and quality of the drilled hole [15].

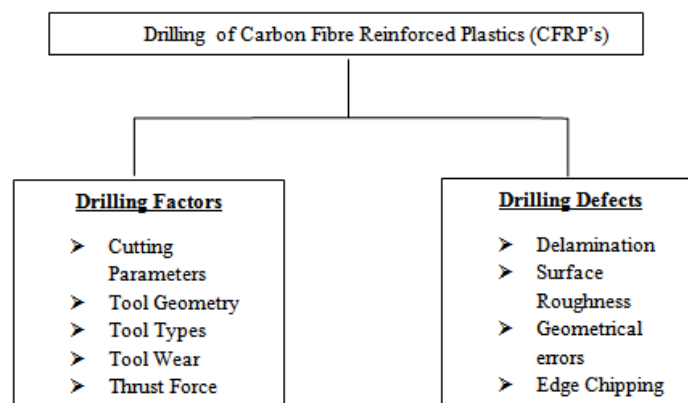


Figure 1: Research Area in Drilling CFRP Composite

Delamination Mechanism in CFRP Composite

Delamination is the most common and serious damage caused during drilling of composite materials and considered as the limiting factor in the drilling process of FRP [16]. It is defined as the separation of adjacent composite plies and characterized by the formation of inter laminar cracks in the material. This damage occurs during drilling, on the hole entrance (peel-up delamination) as well as at the hole exit side (push-down delamination) as illustrated in Figure. 3. Peel-up delamination (Figure 3. a) is a consequence of cutting force pushing the abraded and cut material to the flat surface. Push – down delamination (Figure 3. b) is a damage that occurs in interlaminar regions, so it depends not only on the fibre nature, but also on the resin type properties. This damage is the consequence of the compressive thrust force that

the drill bit edge always exerts on the uncut laminate plies [17]. Delamination (F_d) can be defined as the ratio of maximum diameter to the nominal diameter of the hole as present in the below equation [18].

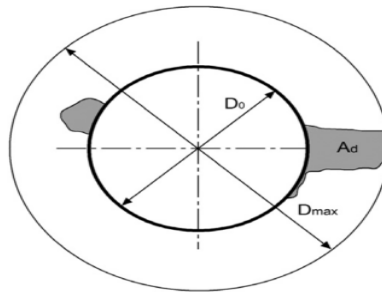
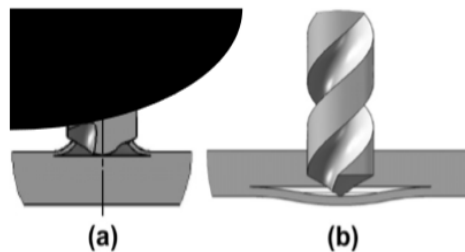


Figure 2: Schematic Representation of the Geometric Parameters [6]

$$F_d = \frac{D_{max}}{D_0}$$



**Figure 3: Delamination Mechanisms: A) Peel – Up Delamination at Entrance
B) Push – Down Delamination At Exit [11]**

Where D_{max} denotes the maximum diameter of the damaged hole,

D_0 denotes the nominal diameter of the hole.

Effect of Drilling Factors on Delamination

The drilling parameters such as spindle speed and feed rate highly influence the cutting forces and delamination in the drilling of CFRP laminates. The cutting forces decrease with the higher cutting speed and increase with the increasing feed rate, drill size [19].[20] Had investigated the different factors affecting the delamination, the drill diameter is the cutting parameter which has greater influence on delamination (88.39%) during drilling of CFRP composite materials. Babu and sunny [21] presented delamination study of composite materials by conducting drilling experiments using Taguchi's L25, 5-level orthogonal array; ANOVA was used to analyze the data obtained from the experiments and finally determine the optimal drilling parameters in drilling GFRP composite materials. Experiments conducted to determine whether varying feed and spindle speed during drilling could reduce the delamination. Wei Y [22] have conducted experiments on the carbon fibre reinforced plastic and Ti alloy stacks and reveals drilling forces increased with the elevation of feed rate, but had uncertain interactive relationships with cutting speed. Delamination area can reduced with lower feed rate and delamination will suddenly increase a lot after feed rate is over a critical value. Vijayan Krishnaraj [23] had reported an experimental investigation on thin CFRP using K20 carbide drill by varying various input parameters optimized using genetic algorithm. Achieved optimized values for spindle speed and feed rate are 12,000 rpm and 0.137 mm/rev respectively. Sinan Al-wandi [24] experimental and simulation results indicated that thrust force and torque

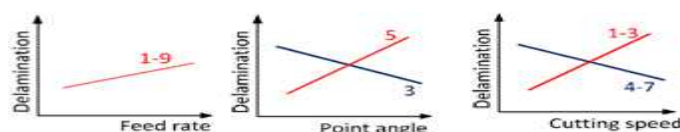
increased with the increase in feed rate and decreased with the increase in spindle speed. In addition, results showed delamination increases with the increase of feed rate and decreases with the spindle speed, as delamination increased drastically when feed rate is over 500 mm/min. In addition, presented results showed in the double point angle drill had less delamination than the twist drill. Y. Turkey [25] had performed the orthogonal machining operation on CFRP composite, the most damaged areas noticed at the hole exit since an impregnation problem has been encountered.

Table 1: Effect of Inputs on the Responses

Sl. No	Input Factor Change	Effect on Response	Reason
1	Increase in Speed	Thrust force and surface roughness decreases.	At higher spindle speeds the cutting tool rubs around the hole wall more frequently causing higher distortions which increase the circularity error [35, 41, 44, 46].
2	Increase in feed	Thrust force and surface roughness and damage increases.	At high feed, the tool enters the work faster, thus increasing the thrust force. The faster entry of the tool damages the inner surface decreases the surface roughness [36,37,38]
3	Increase in Point angle	Thrust force and damage increases. No clear trend for Surface roughness	At high point angles, the surface-to-surface contact between the cutting edge and work increases. The increase in thrust also increases the damage [38,39,40,41]
4	Increase in Tool diameter	Thrust force increases. No clear trend for Surface roughness	As diameter increases, the contact area of the tool with the work increases and thus elevates the thrust force [37,42,43,45]

Effect of Drilling Factors on Thrust Force, Surface Roughness and Torque

S D S [26] conducted experiments on the bi directional CFRP and optimized the process parameters with Taguchi method, 4mm drill bit diameter and 1800 rpm spindle speed shows the minimum thrust force and surface roughness. Gong-Dong Wang [27] compared twist pilot hole and step-drill bit on influence of carbon fiber reinforcement polymer, conclude that conventional drilling by use of twist drill may not be the appropriate method to drill laminates as it records the highest thrust forces both at low and high feed rates. A. Caggiano[28] had presented the image analysis for the CFRP drilled hole arrangement. N. Feito[29] developed the numerical model to predict the thrust force response on the carbon wovenlaminates. A. N. AMIR [30] conducted several experiments on different tool geometry along with different speeds to observe the thrust force, Lowest thrust force obtained from experiment with full back support of 13.7 N. Different design of back plates giving slightly different results for torque. Kumar D [31] did experimental investigation observed that the surface roughness at a feed rate of 0.10 mm/ rev was higher than that at a feed rate 0.02 mm/rev, using solid carbide eight-facet drill. QingxunMeng[11] had developed a new analytical model to predict the instantaneous thrust force of drilling the laminate composite materials which has different stack sequence. Y. Turki[25] performed orthogonal drilling on the carbon epoxy composite, the fiber orientation relative to the cutting speed direction is a key factor which determines the surface quality in drilling.



1 Davim et al. [51, 52, 53]

2 Kilickap [54]

2. Rsardinas et al. [53]

4 Gaitonde et al. [55,56]

3	Rubio et al.[57]	6	Rawat et al [58]
4	Tsao et al.[59]	8	Arul st al.[60]

Figure 4: Effects of Input Variables on Delamination when Drilling Composite Laminates**Effect of Tool Geometry and Materials On Delamination, Thrust Force and Surface Roughness**

Drill geometry such as point angle and helix angle have high importance in effecting delamination when drilling CFRP; small point angle and low helix angle are preferred for good hole entrance [24]. Sinan Al-wandi [24] had compared twist drill and double point angle drill having same helix angle with different point angle, results showed that double point angle drill had less delamination than the twist drill. Jamel Saoudi[33] proposed realistic model to predict critical thrust force responsible for drilling-induced exit-ply delamination in a multi-directional carbon fibre-reinforced plastic laminate with core drill. [34] Presented the diamond drill provides slightly better results than the TiN/TiAlN drill. Kumar D [31] compared three drill bits HSS drill, solid carbide eight-facet drill and Carbide tipped straight shank (K20) drill on GFRP and recommended solid carbide eight-facet drill for drilling. [6] Analyzed the better surface finish is observed with SPUR drill with spindle speed of 6750 rpm and a feed rate of 2025 mm/min.

OPTIMIZATION OF DRILLING PROCESS PARAMETERS

Selection of optimum parameters during machining the component is an important task for manufacturing industries. Machining under optimum conditions will eliminate unnecessary experimentation and reduces the labor and operating cost. Hence, in order to find out the optimum conditions, several studies made over a period. Shahrajabian H [47] optimized process parameters to achieve good surface finish with the good circularity of the hole at spindle speed of 4000 RPM, feed rate of 50 mm/min, and tool angle point of 100 degrees. Geier N [48] had optimized the cutting speed of 50 (m/min), feed rate of 0.049 (mm/rev) and a screw pitch of the feeding helix of 3 (mm) produce good-quality holes with orbital drilling. Voss R [49] optimized values of High cutting velocities and feed rates in the range of $v_c = 200$ m/min and $f = 100$ mm/rot generate better machining quality. Submitted H M A I [50] numerically optimized the process parameters on the conventional machining of GFRP.

Table 2: Optimum Conditions Explored from Previous Studies

Sl. No	Authors	Responses Explored	Optimum Conditions	Ref.
1	Dhirajkumar et. al	Thrust Force, Delamination, Surface Roughness	Speed = 2000 rpm Feed = 0.1 mm/rev and Solid carbide drill bit	61
2	N. Geier and T. Szalay	Cutting Force, Delamination, Surface Roughness	speed = 50 mm/min, Feed = 0.049 mm/rev and Screw pitch of feeding helix= 3mm	62
3	D. S. S	Thurst Force, Surface Roughness	Speed = 1800rpm, Feed = 10mm/min, Point angle = 90^0 , Drill diameter = 4mm	63
4	K. Abhishek et. al	Thurst Force, Delamination and Torque	Speed = 2800rpm, Feed = 50mm/min, Drill diameter = 5 mm	64
5	Feito et al.	Delamination	Speed : 25–100 m/min, feed : 0.05 mm/rev, point angle : 90^0 – 108^0	65
6	Faraz and Biermann ⁴	Thrust force and delamination	Speed : 80 m/min feed : 0.35 mm/rev	66
7	V. N. Gaitonde et.al	Delamination	Speed: 4000 rpm Feed:1000 mm/min Point angle: 85^0	67

Table 2: Contd.,				
8	B. Latha et. al	Delamination	Speed:1500rpm Feed:50mm=min Drill diameter:6mm	68

CONCLUSIONS

This review work on fiber reinforced polymer composites under the influential factor is effectively studied. From the above work, it is concluded follow

- The delamination factor on exit is more than the entry panel of drill bit. Because the compression action takes place between the fiber at entry level and bush out of fibers happened at exit level of drill bit. This deviation happed because of direction of cutting tool to work
- The delamination effect on FRP composites reduced by proper selection of parameters and its level.
- The selection of factor levels for machining plays an important role during machining and selection of optimum levels helps the manufacturing firms to choose the correct machining conditions.
- Selection of appropriate statistical tool is also very important during optimization. It is taken based on the available input and output factors for drilling.
- Therefore, in order to produce defect free holes and mechanical joining of composite structures, the process of drilling on CFRP composite laminates needs monitored with in-depth planned experimentations.

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